Resolution of Mainlobe and Sidelobe Detections using Model Order Determination

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Adaptive Sensor Array Processing Workshop (ASAP)

March 13-14, 2001

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **14 MAR 2001**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Resolution of Mainlobe and Sidelobe Detections using Model Order Determination**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Amin G. Jaffer; Joe C. Chen; Thomas W. Miller**	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Raytheon**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **Defense Advanced Research Projects Agency 3701 North Fairfax Drive Arlington, VA 22203-1714**	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See ADM001263 for entire Adaptive Sensor Array Processing Workshop., The original document contains color images.

14. ABSTRACT
See briefing slides.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**24**	

False Sidelobe and Multiple Target Resolution Problem

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- Adaptive beamforming/filtering and STAP methods can result in high sidelobe levels, especially with limited sample support for estimating interference covariance matrix
- This can cause excessive "false" sidelobe detections arising from targets or undernulled interferences
- Sidelobe rejection capabilities of adaptive matched filter (AMF), generalized likelihood ratio test (GLRT) and AMF/ACE have been previously analyzed

Multiple Target and Sidelobe Detection using Weighted Least-Squares Fit to AMF and GLRT Data

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- For simplicity of exposition, we will consider the spatial domain only although the method is directly applicable to the angle-Doppler domain
- The proposed method uses the output detection test statistic computed over the entire angular extent of interest
- In any given range cell the question is whether the totality of output test statisitic values computed over the beam directions of interest that exceed a preset threshold represent one target, two targets or up to a maximum M targets, i.e., the question is one of model order determination

J-amf and J-glrt Functions - Normalized Adaptive Array Outputs

- **J-amf(θ) represents the normalized adaptive array power output as a function of the angle θ**

$$J_{AMF}(\theta) = \frac{\left| d^H(\theta)\hat{R}^{-1}x \right|^2}{d^H(\theta)\hat{R}^{-1}d(\theta)} = \frac{\left| w^H(\theta)x \right|^2}{w^H(\theta)\hat{R}w(\theta)}$$

- **J-glrt(θ) is J-amf(θ) further normalized by data power term**

$$J_{GLRT}(\theta) = \frac{J_{AMF}(\theta)}{1 + x^H \hat{R}^{-1} x / K}$$

- $$\hat{R} = \frac{1}{K}\sum_{k=1}^{K} x_k x_k^H \qquad x_k\text{'s are secondary set of signal-free data}$$

K - - Number of snapshots

Normalized Adaptive Array Outputs
- - - continued

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- **Diagonal Loading and shaded (tapered) steering vector:**

$$\hat{R}_{DL} = \hat{R} + aI$$

$$d_{sh} = w_{sh} \cdot d, \quad \cdot \textit{ represents the Schur product}, \; w_{sh} \textit{ is a shading or taper function}$$

- $w(q) = \hat{R}_{DL}^{-1} d_{sh}$ **is also used in the J-amf(q) and J-glrt(q) functions**

J-amf Function for One and Two Targets - - - No Taper, K=100

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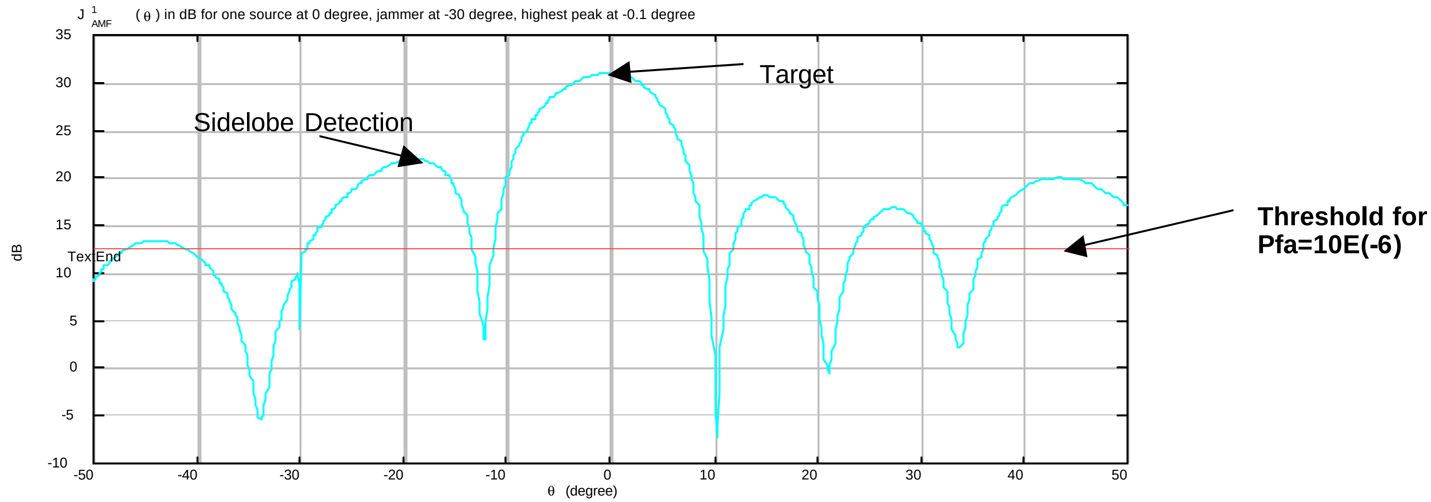

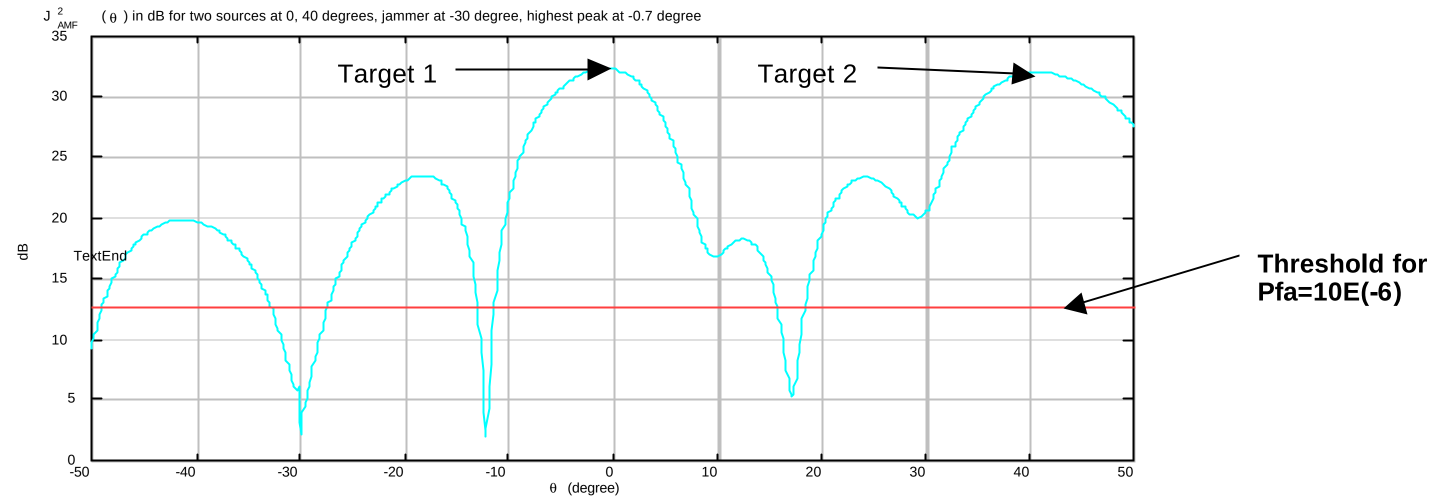

J-amf function -- unshaded steering vector and 50 dB Chebyshev taper

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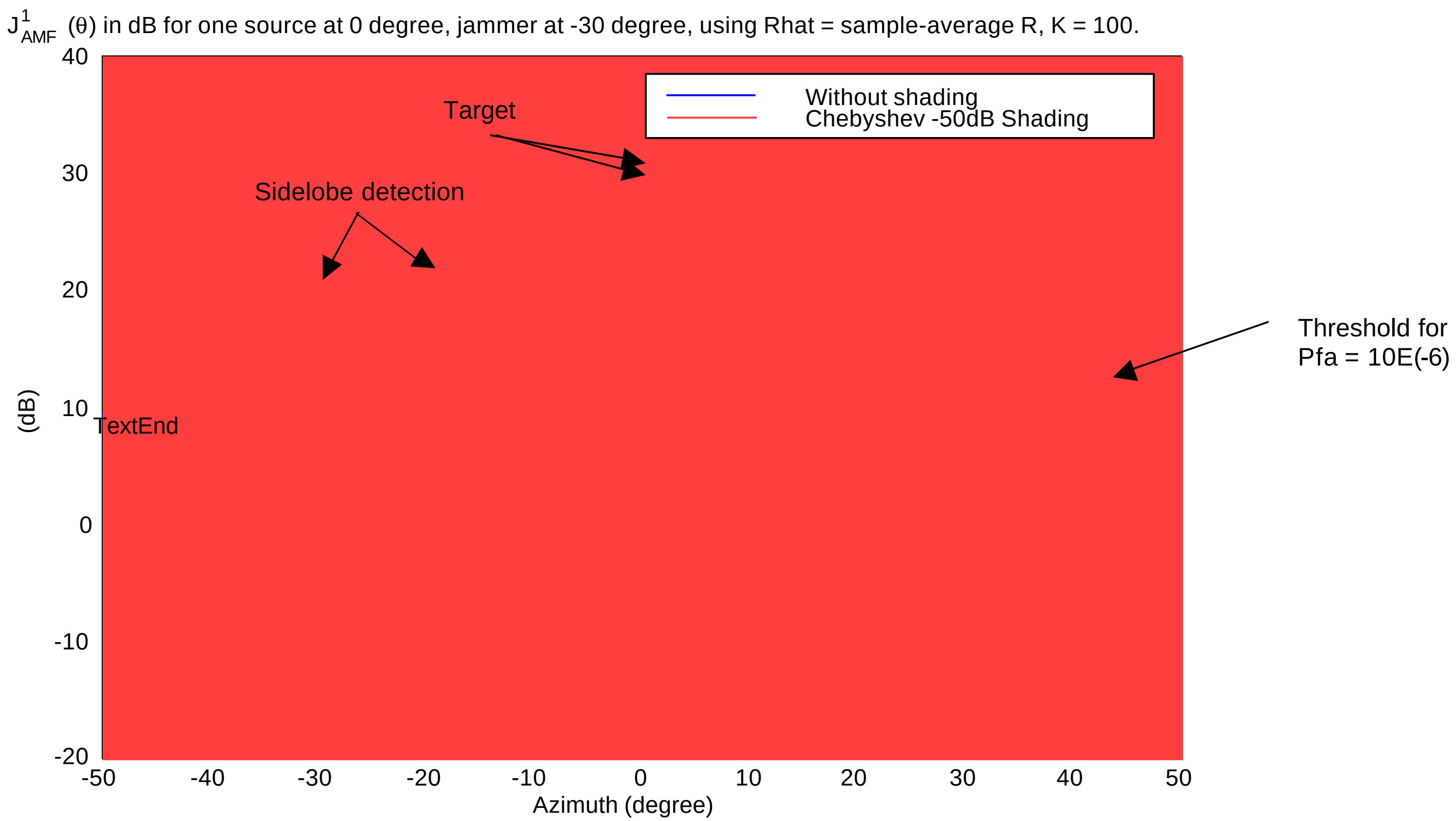

- False sidelobe detections can occur in adaptive arrays even with 50 dB Chebyshev taper

Weighted Least-Squares and Model Order Determination Method

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- **Determine L peaks (or values adjacent to peaks) of $J_{AMF}(q)$ at $q_1, q_2, ..., q_L$ which exceed preset threshold for given P_{FA}**

- **Test data vector x is modeled as**

$$x = D_s a + n$$

where $D_s = \left[d(q_{s1}), d(q_{s2}), ..., d(q_{sM}) \right]$ *an N by M matrix*

a **and** n **are the complex signal amplitude vector and interference plus noise vectors**

- **The application of the weight vector $w(q)$ to the data yields**

$$y(q) = w(q)^H x = w(q)^H D_s a + v$$

WLS Method ......continued

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- **where** $v(q) = w(q)^H n$

$y(q)$ **is evaluated at L distinct points**

- **The transformed signal model is fit to the** $y(q)$ **data in a weighted least-squares sense and the residual is evaluated**

$$\begin{bmatrix} y_1 \\ \cdot \\ \cdot \\ \cdot \\ y_L \end{bmatrix} = \begin{bmatrix} w(q_1)^H D_s a \\ \cdot \\ \cdot \\ \cdot \\ w(q_L)^H D_s a \end{bmatrix} + \begin{bmatrix} v(q_1) \\ \cdot \\ \cdot \\ \cdot \\ v(q_L) \end{bmatrix} \quad \textbf{or} \quad Y = Ha + V$$

- **The residual is computed as**

$$J_{res}\left(q_{s1},\ldots,q_{sM}\right) = \left\| I - P\left(q_{s1},\ldots,q_{sM}\right)\right\|^2$$

WLS Method continued2

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- $P(q_{s1},\ldots,q_{sM})$ is an orthogonal projection operator

  For details, see paper

- $J_{res}(q_{s1},\ldots,q_{sM})$ is a function of $q_{s1},\ldots,q_{sM}$ and needs to be minimized over those angles

- For computer simulation purposes, we limit ourselves to M=2

- As a first approximation, we take q_{s1} *and* q_{s2} to be the two highest peaks --- computationally efficient

- Better approximation -- fix one angle at global peak and search over other to minimize J_{res} - - - more computation

Akaike Information Criterion (AIC) for Model Order Determination

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- **Compute AIC(m) for model order m=1,2,....,M and choose the minimum**

  AIC(m)= J_{res} **+ Number of free parameters in model**
  = J_{res} **+ 3m**

- **Alternate Minimum Description Length (MDL) criterion is not applicable here because the second term (the "penalty" term) becomes zero for single target signal snapshot**

Performance Evaluation by Monte-Carlo Computer Simulation

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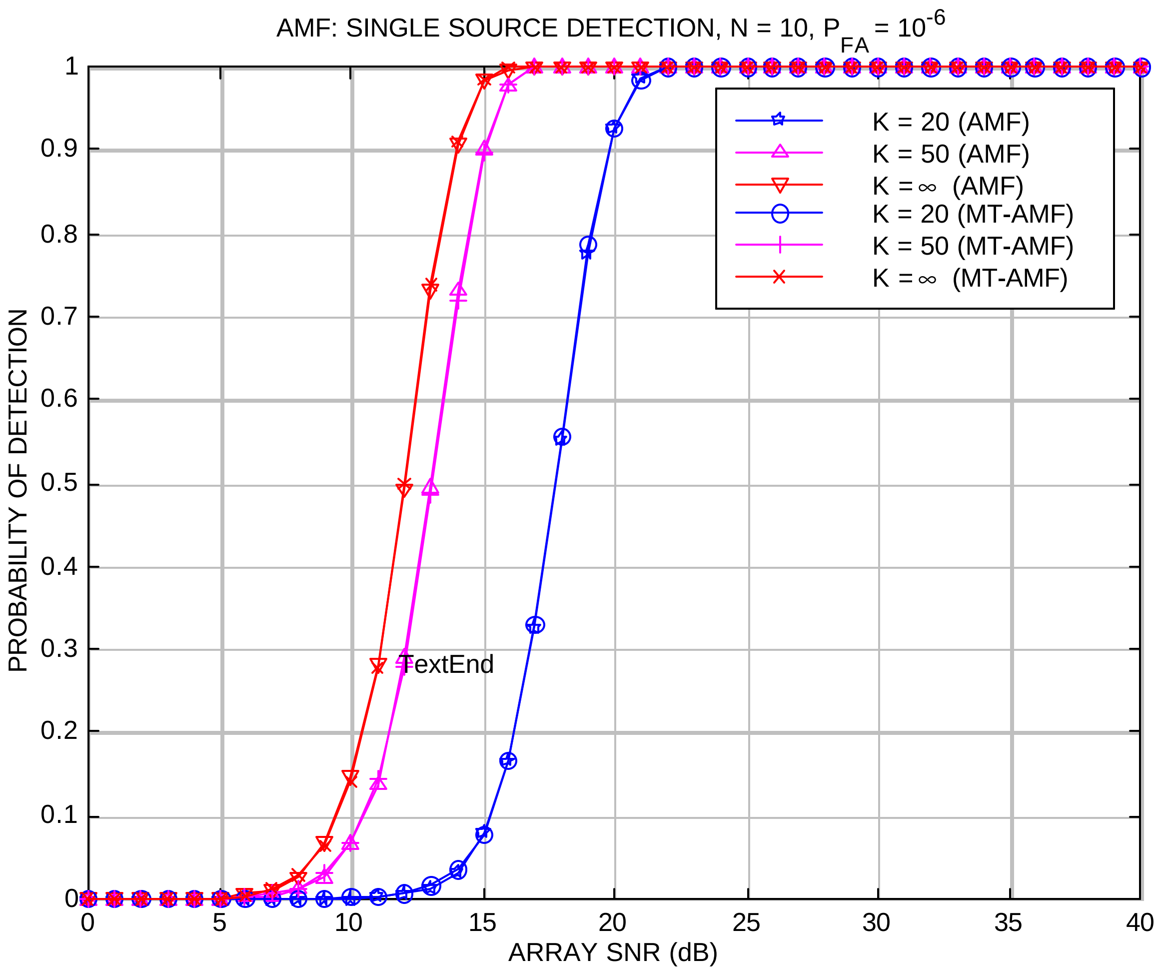
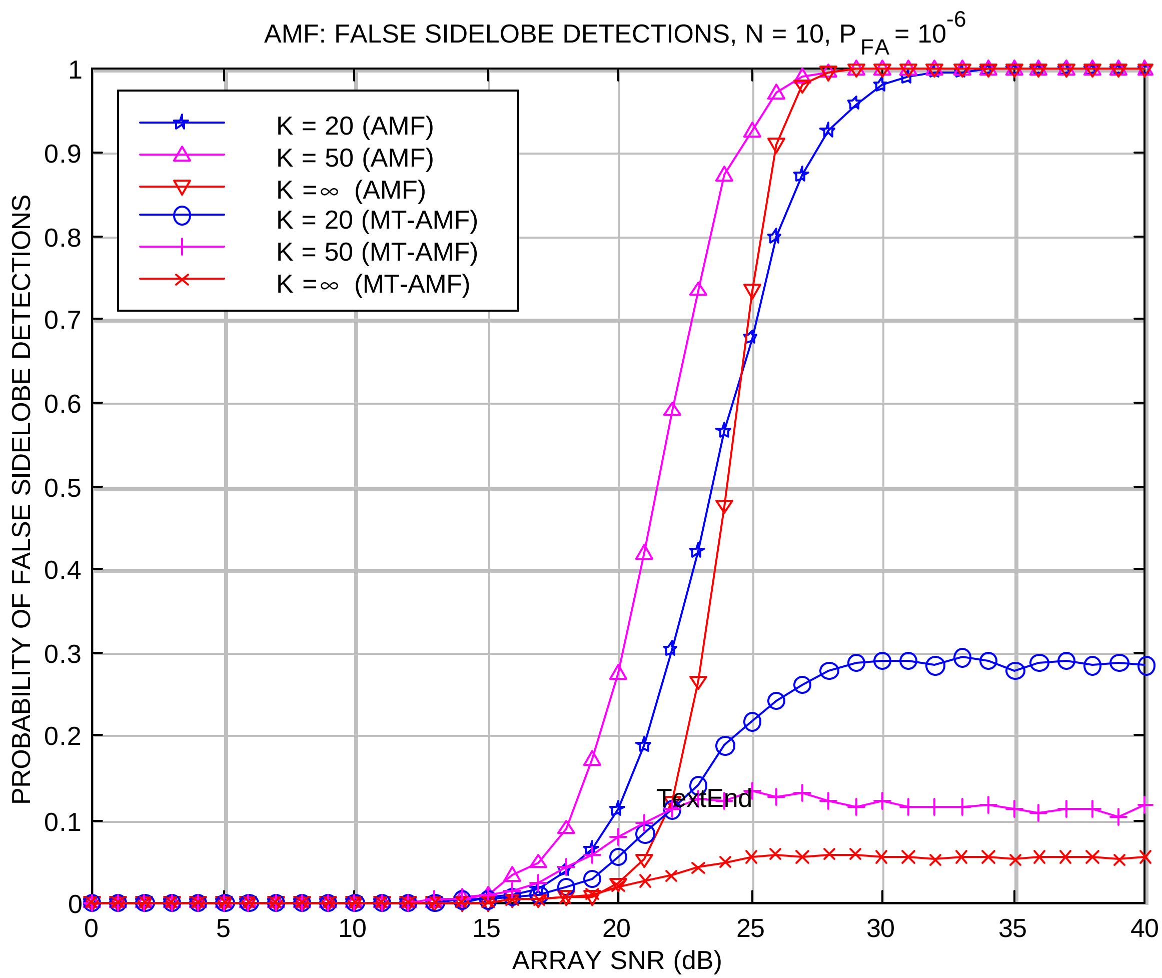
- 10 element line array with half-wavelength inter-element spacing
- Single source placed at 0 degrees (broadside)
  Two sources at 0 and 45 degrees
  Noise jammer placed at -30 degrees, JNR=40dB
- Thresholds for AMF and GLRT methods to yield a specified P_{FA} computed in accordance with paper by F.C. Robey et.al.,

  IEEE Trans. on AES, March 1992
- The probability of detection was based on 5000 trials for each point on the curve
- A target detection was considered valid if it fell within plus or minus 3 dB beamwidth of the true target angle

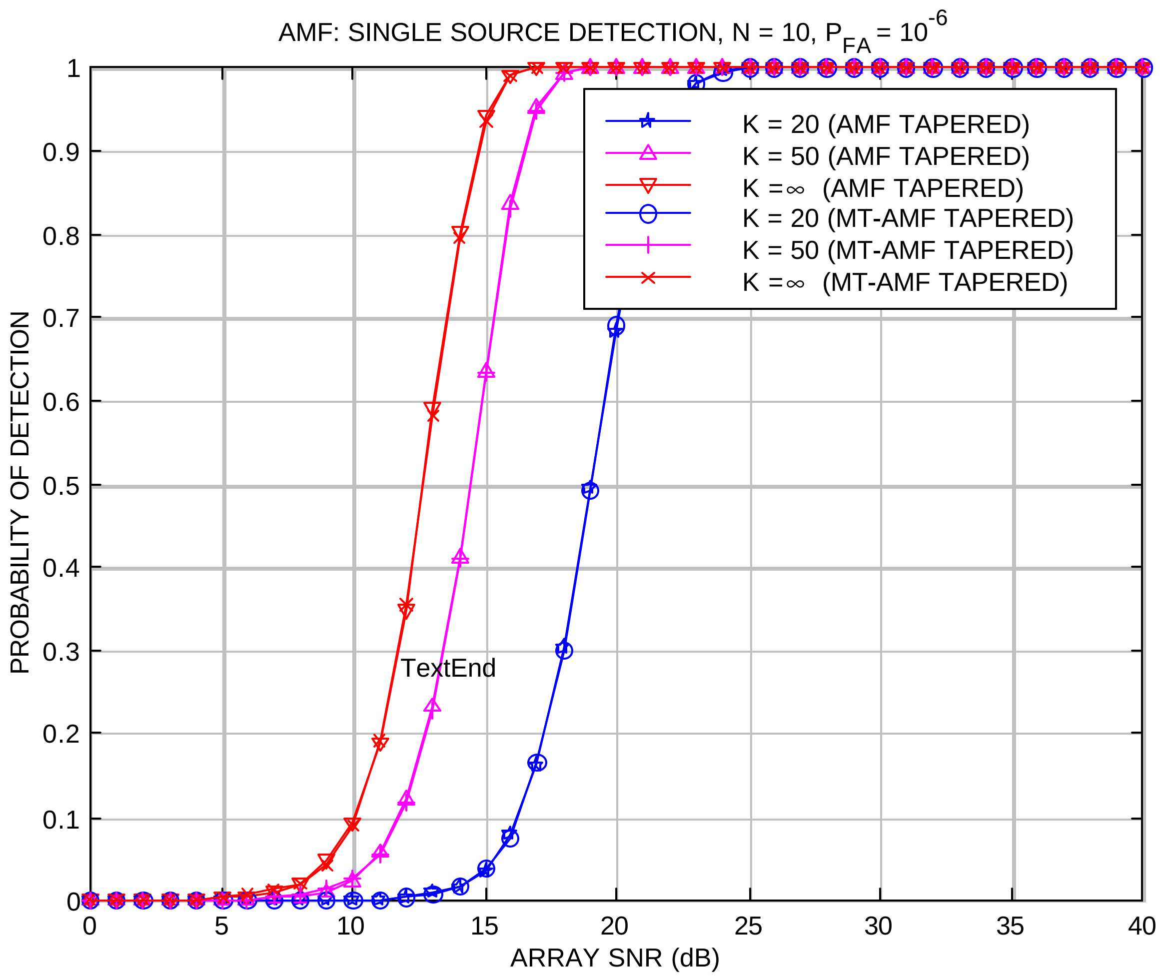
Probability of Mainlobe Detection (AMF)



Probability of Sidelobe Detections (AMF)



Probability of Mainlobe Detection
- - - AMF Taper



Probability of Sidelobe Detection
- - - AMF Taper

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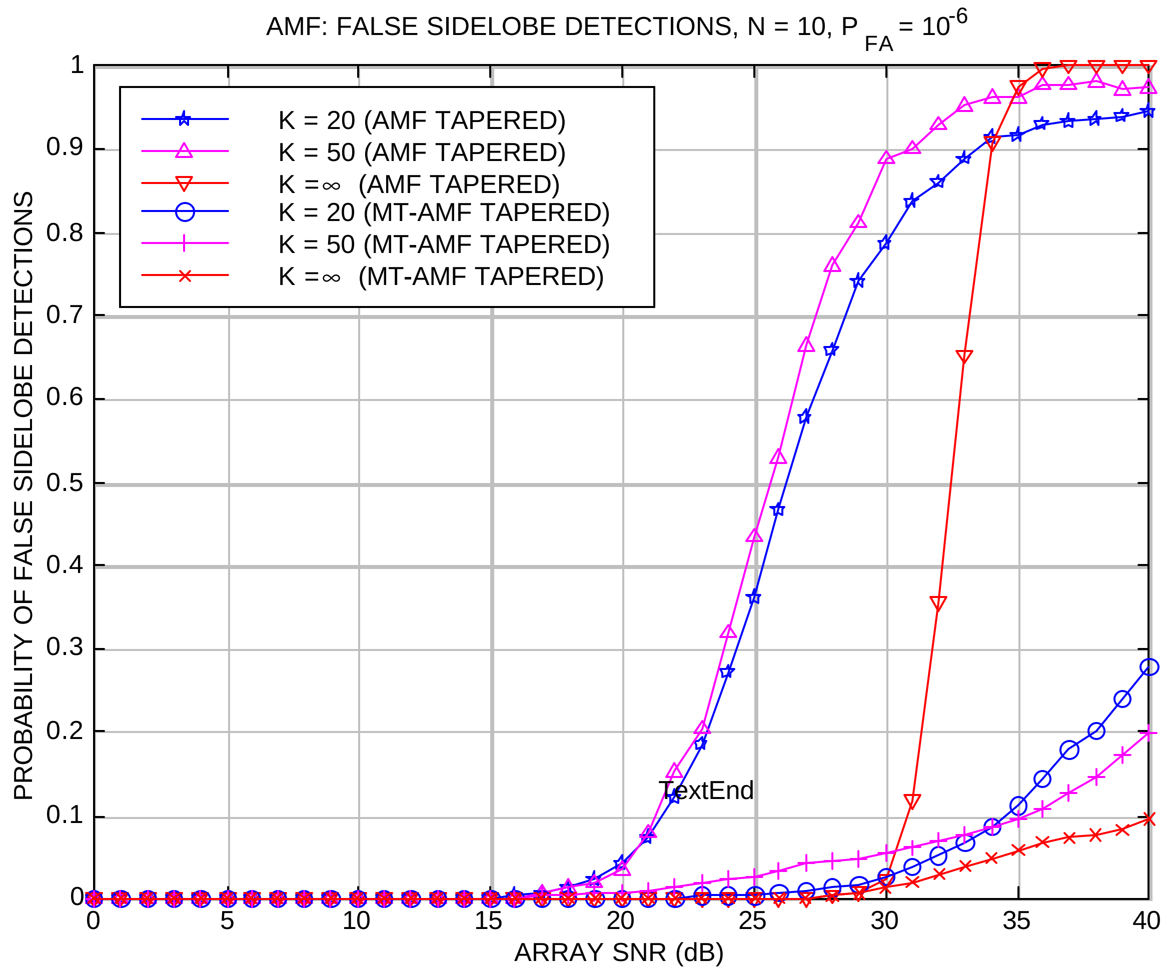

Probability of Mainlobe Detection
AMF Taper plus Diagonal Loading

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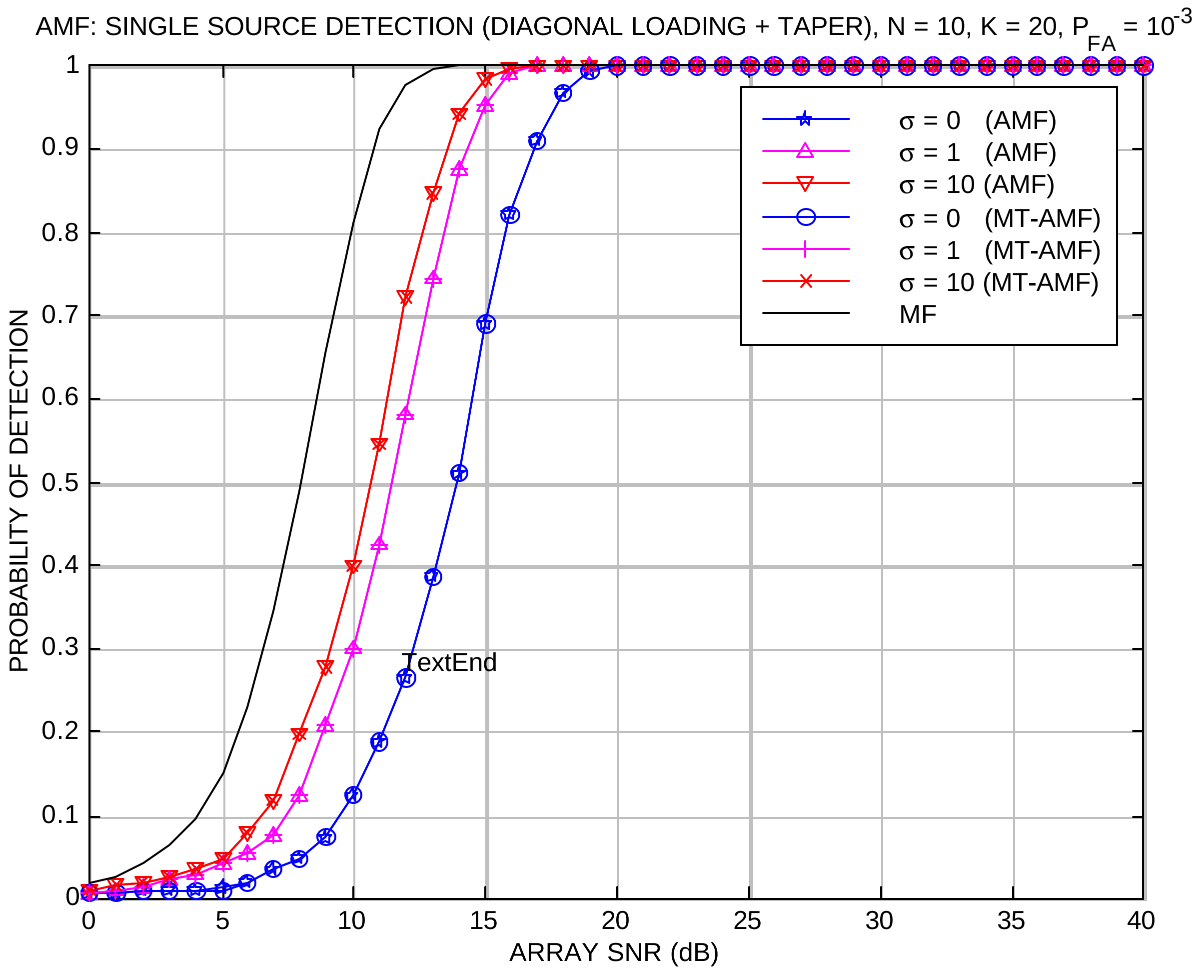
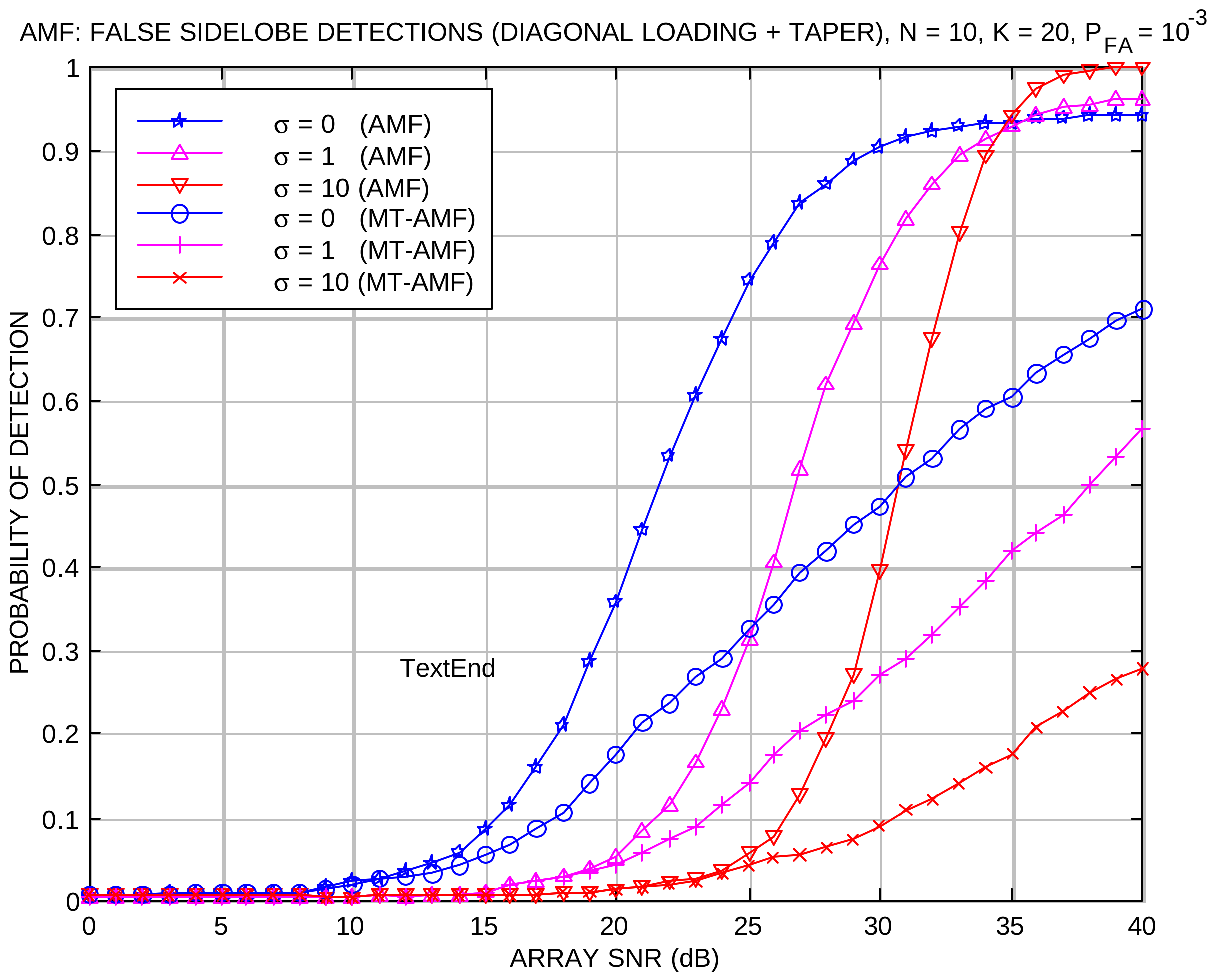
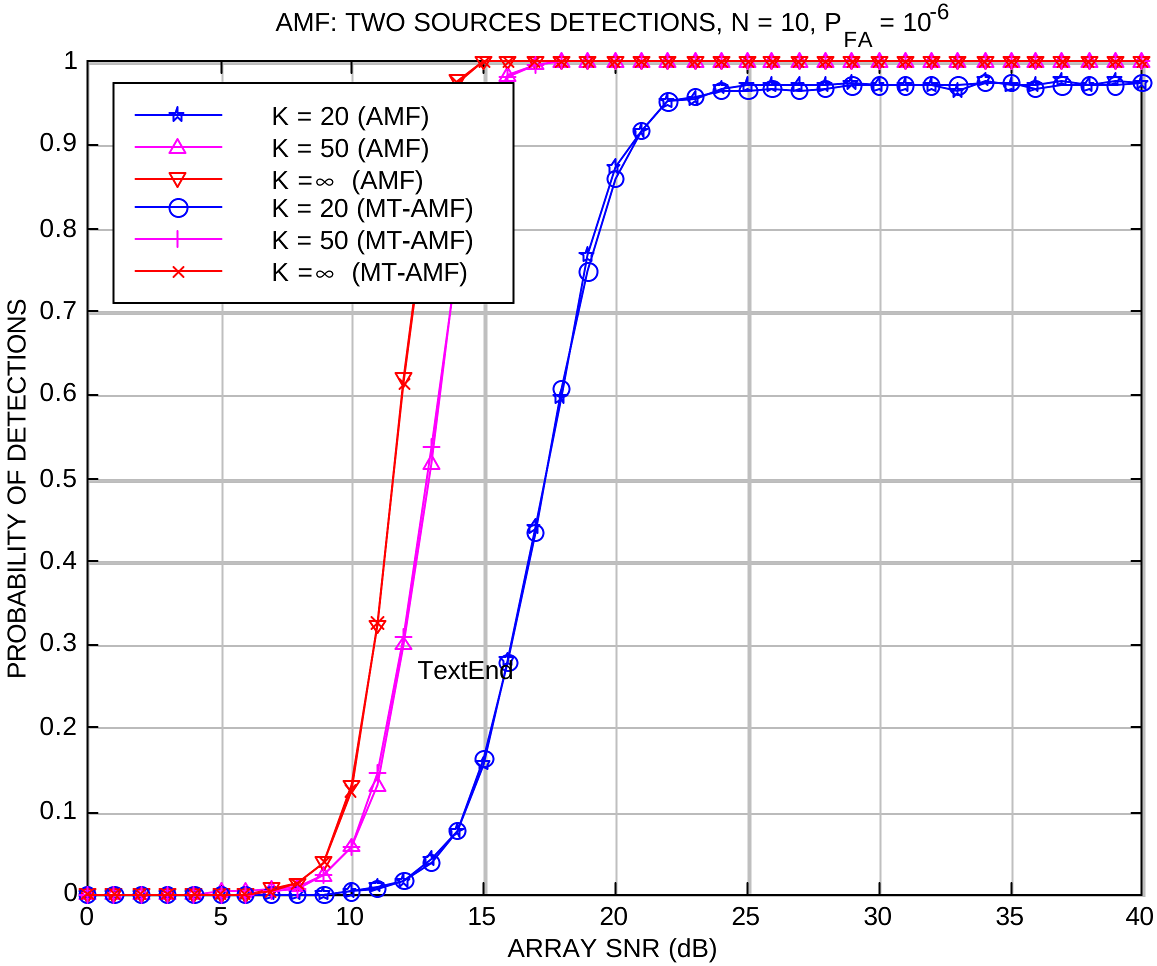


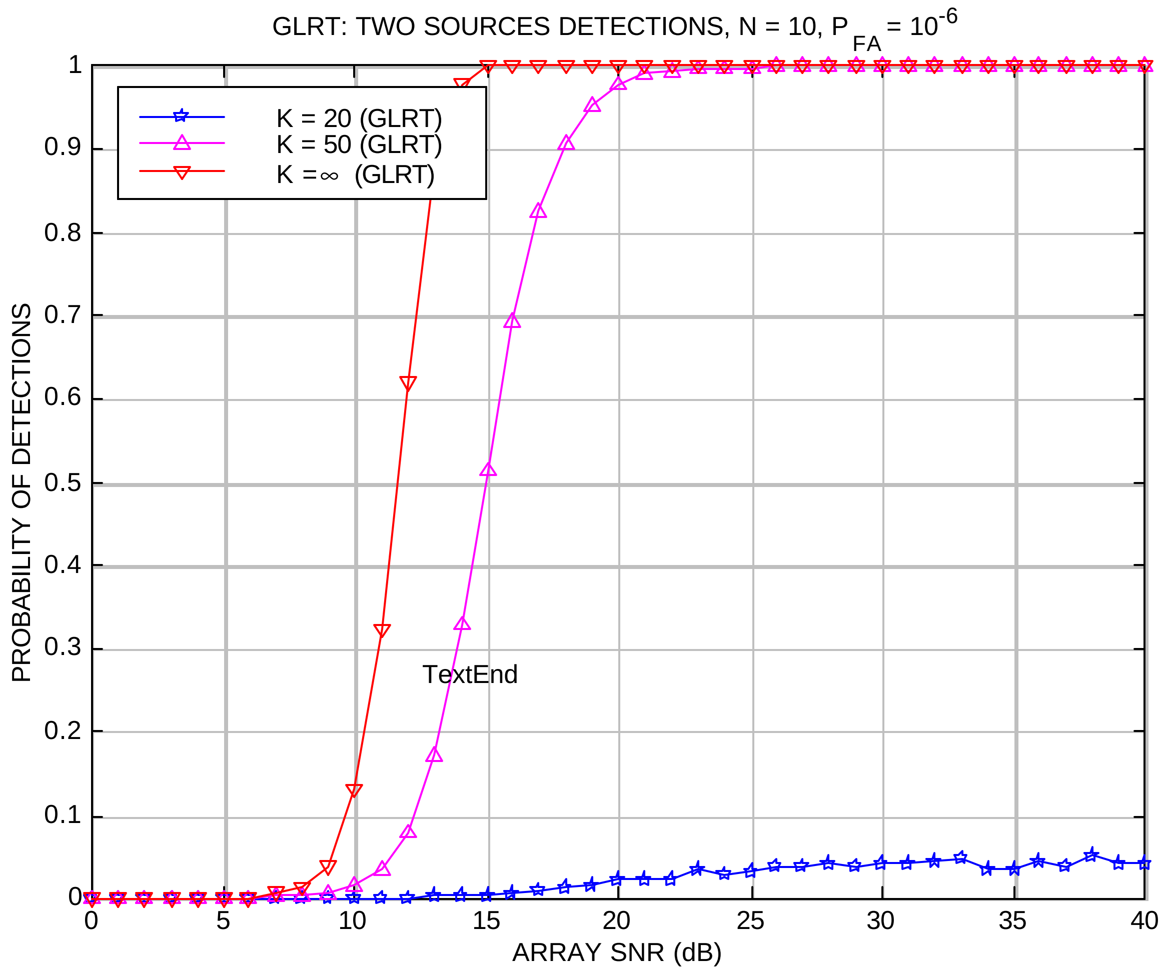
Probabilty of Sidelobe Detection
AMF Taper plus Diagonal Loading



Probability of Detecting Two Sources - AMF



Probability of Detecting Two sources - GLRT



Probability of Detection - - GLRT

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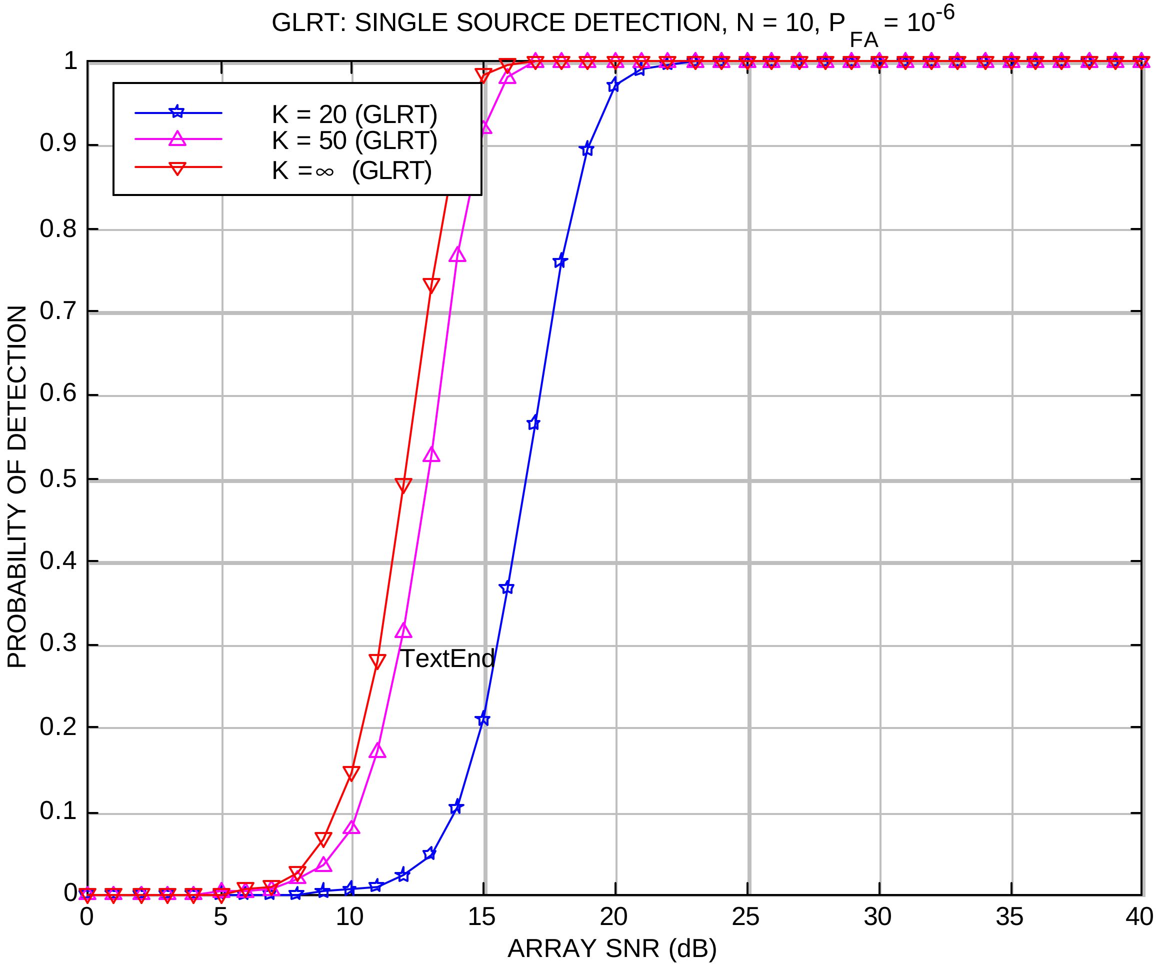

Probability of Sidelobe Detection - - GLRT

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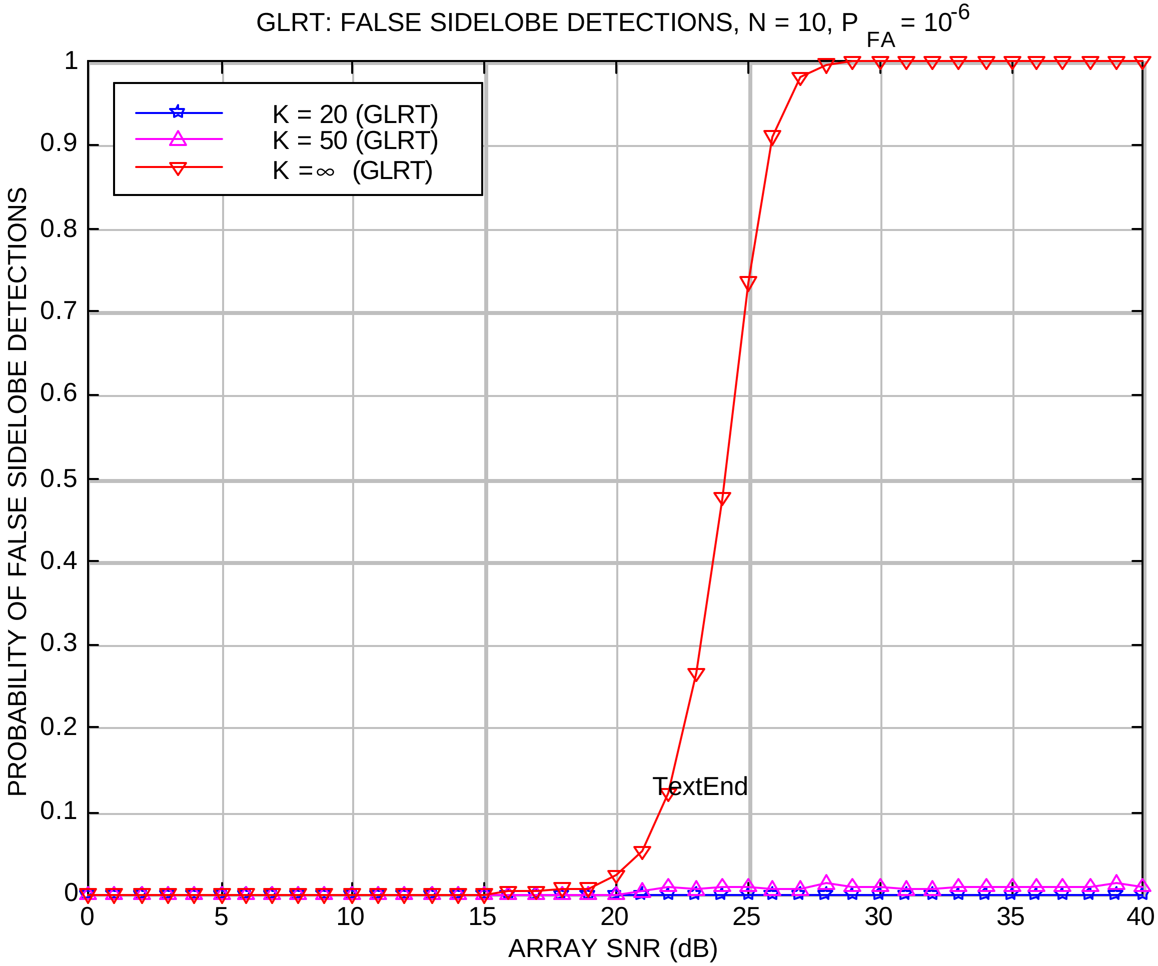
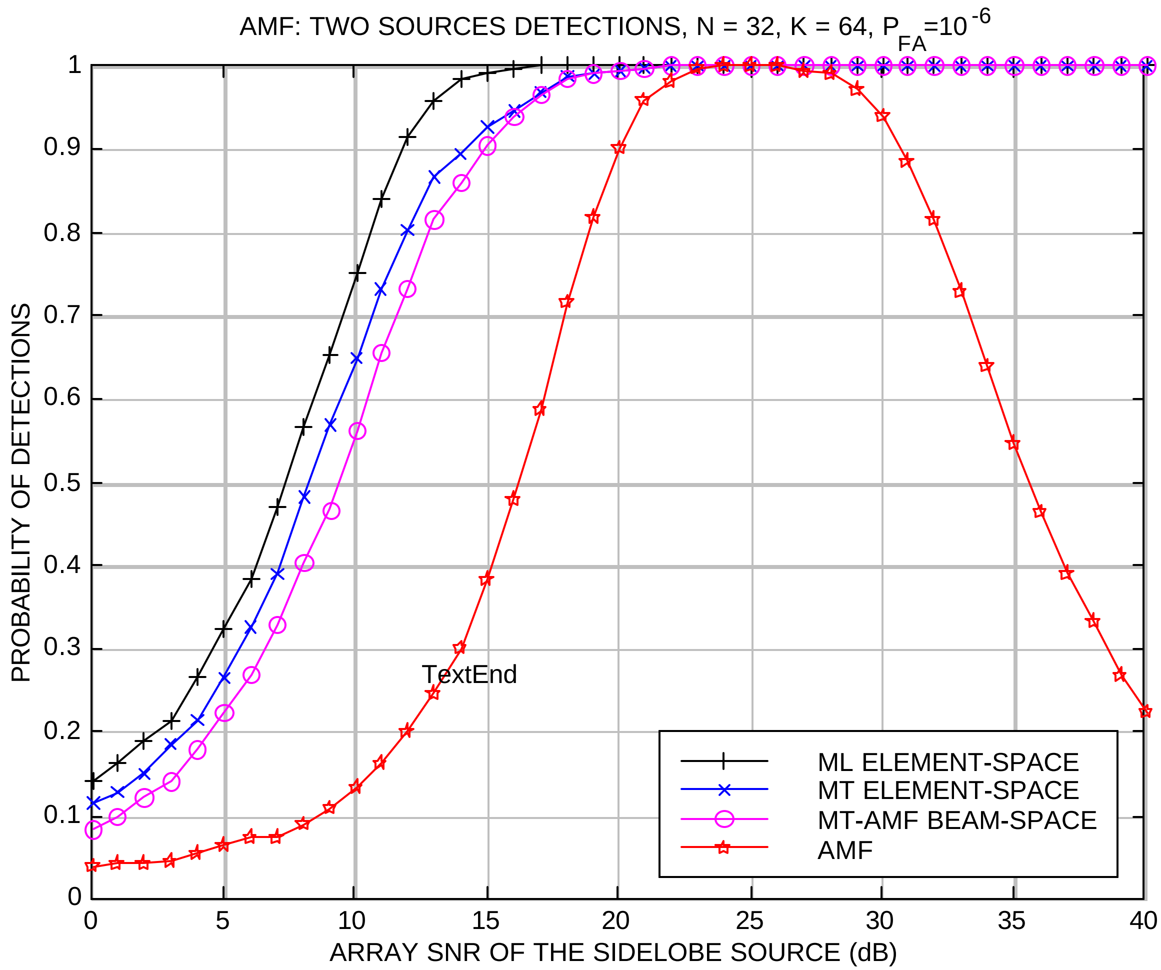


Probability of Detecting Two Sources - - - Various MT-AMF methods



Conclusions

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- Proposed new method, using weighted least-squares fit to AMF or GLRT data combined with model order determination by Akaike Information Criterion, can significantly reduce false sidelobe detections

- This is true even when amplitude taper and diagonal loading is used

- The approximate method for angle estimation is computationally efficient and yields good detection and sidelobe rejection results